Seeds of Opportunity
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Securing Global Supplies of Safe and Nutritious Foods Through Biotechnology and Breeding

T. Michael A. WILSON, CEO, HRI, UK

After 10,000 years of empirical selection, 100 years of random accelerated breeding [including chemical/gamma-radiation mutagenesis (FAO-IAEA records 2252 irradiated crop varieties (1790 in 1995) of 154 spp. in >50 countries), embryo rescue, interspecific hybrids and so forth; each mixing 30,000 genes at a time in unpredictable ways], over 50 years of intensive, agrichemical-dependent production, and 20 years of R&D into precise and specific gene transfer (GM/GE) techniques, Mankind now has the opportunity to use sound knowledge-based biotechnology and genetics to develop crop seeds specifically targeted at more efficient, higher-yielding, lower input sustainable agriculture**.**

Of all 250,000 recognised plant species, only about 1000 were selected, inevitably through trial and error, by our ancestors for food. Selective breeding slowly created very weak, uncompetitive (non-weedy) food crops which require intensive labour or chemical inputs to protect them from insects, weeds, pests and an assault of pathogens. Nonetheless, diseases and pests still cause huge pre- and post-harvest losses (global average estimated at 30%; but locally 100% especially in LDCs). Hence famines and epidemics continue; “Mother Nature is most certainly NOT benign”.

Only 8 plant (and 7 animal) species now “feed” over 90% of the global population of 6+ billionn (top 4 crops = wheat, rice, maize, potato).

Orphan crops (e.g. cassava) are excellent targets for GM; having the greatest positive impact on rural poor, subsistence farmers. Farming transgenic crops is NOT scale-dependent (e.g. the 1000’s of small cotton farms in Heibei, China). It is a very versatile, transferable technology.

By 2025, total food demand will have risen by 50% from today, from 2 to 3 bn tonnes.

Many “green revolution” crop varieties are now plateau-ing or even declining in yield. So, we urgently need new yield-enhancing technologies and greater genetic diversity (restore older landraces and varieties) to ensure:

(a) In the Developed World: high-yield, high-quality, sustainable, reproducible, intensive, efficient production with minimum negative environmental impacts, using the minimum cultivated area.

and, (b) In the Developing World: to provide food security and alleviate poverty (generate income) among poor subsistence farmers (70% of poor) and urban consumers (30% of poor).

Also better (GM) crops can avert human and environmental toxicity from unprotected manual applications of older, cheaper more hazardous (Category 1) agrichemicals (when they can be afforded!). The poor spend >80% of their income on food. Hence, agricultural biotechnology and yield growth are not optional for LDCs. 53% of Indian population depend on agriculture for a livelihood (total population of India = 1.0bn rising to 1.5 bn). Also 80% of the 30 million Kenyans are small-scale farmers.

Urban populatons will rise two-fold (to 3.6 bn) over the next 20 years (40% of sub-Saharan Africa’s poor were urban in 2000).

Over the last 30-40 years, agricultural research has alleviated poverty, and famine. In India, poverty declined from 53% to 33% between 1973-1993 (and averted predicted famines). It is a fiction to believe that going back to traditional methods or ancient crops can feed the world - or that GM will solve everything. We need the best of all technologies, and quickly. Recent studies on the impacts on the global environment of extending today’s agricultural practices to achieve the necessary food outputs in 20 and 50 years time makes sombre reading. Widespread organic farming would make things worse.

Yield Issues

In Asia, rice yields must increase by 50% even as arable land area declines. There is a biophysical limit to yield; the photosynthetic efficiency of the crop. Researchers presently trying to introduce maize-like C4 photosynthetic pathway into rice (which also improves the efficiency of water use).

Even with agricultural research, globally, over 30% (>50% in LDCs) of pre-harvest crop yield is still lost to diseases (pathogens = fungi, bacteria, viruses, viroids, phytoplasmas) and/or pests [insects, birds, nematodes and competition with weeds (e.g. Striga infests 40% all arable land in Africa)].
Potato late blight alone costs $3 billion p.a. in lost crops and chemical control inputs.

Likewise, annual losses to insect pests alone in rice/cereals are 10-35%, even with £2.5 bn spent on rice pesticides. Transgenic rice is now available with engineered resistance to tungro virus, or to rice yellow mottle virus. This can use a small fragment of the cognate viral genetic sequence (20-200 nucleotides only) which does not encode any protein (allergenic or not!) and operates by a natural plant biochemical pathway called gene silencing. GM rice has also been made to be resistant to nematodes (using a natural maize cystatin gene which interferes with the worms digestive system, but is harmless to mammals).

Over 50% of Uganda's cassava crop was lost to a new strain of whitefly-transmitted African Cassava Mosaic Virus (ACMV) and to green mite in 1980s. Evidence of co-evolution, or the genetic cat-and-mouse game that plant breeders have played blindfolded until the past 100 years, and now with greater precision and knowledge than ever before.

Global losses due to weeds stand at 10-15% (in both food and cash crops). In LDCs 18-20% of the cotton crop is lost to weed competition (twice that in the Developed world).

GM, genomics, marker-assisted breeding and allied methods can provide swift and targeted resistance gene stacking to handle multiple pest or disease problems in local areas.

* African groundnut rosette virus; aphid-transmitted; limited natural resistance gene(s) in long-season cultivars, not short season ones which farmers prefer. Years of selective breeding (at ICRISAT) have now overcome this; but how quickly will the virus complex evolve to overcome the plant's resistance? No natural resistance gene(s) have been found in ICRISAT's extensive germplasm banks of plant material against peanut stripe virus or Indian peanut clump virus (which is persistently transmitted by a soil-borne fungus). Not uncommon situation. Easy to develop GM peanuts with a short virus-derived sequence or a dysfunctional gene to

confer resistance. Easier than controlling the soil fungal vector (with methyl bromide) or the insect vectors (with sprays).

* Chinese wheat virus story - SBWMV natural field deletion or WYMV plus Chinese SBWMV (mixed infections common).

* Papaya ringspot virus resistant CP transgenics in Hawaii and Johor (Malaysia) Eksotika papayas (MARDI).

* New forms of crop protection. Biochemical pesticides or natural elicitors, that switch on endogenous R-gene pathways (sometimes over 50 endogenous crop plant genes). E.g. *Erwinia amylovora* harpin-signalling pathway(s). Very wide spectrum protection, growth enhancement and a very short environmental half-life. No residue. Would be excellent for organic farming, yet made by cloning of the *E.a.* harpin gene in *E. coli* K12, which is then lysed, and a crude prep sprayed at 15g/acre in starch (150g) in water (not unlike organically approved *Bacillus thuringiensis* cell extracts).

* Wheat stem/leaf rusts most intractible pathogens. In 1800's India, one devastating epidemic/famine occurred on average *per* decade. Now have high-yielding semi-dwarf wheats and HY rice varieties with multiple resistance genes made through decades of careful accelerated, recurrent selective breeding. But need to move faster. OECD predicts wheat and coarse grains (barley & corn; 40% used for malting or animal feed) outputs to rise by 11-13% by 2006, (21-34% in Argentina), but global consumption will overtake wheat production in 2006.

Abiotic Stresses: heat, cold, drought, salinity, aluminium toxicity (acid soils), soil erosion or degradation, alkalinity (poor iron availability, one-third of all arable land is too alkaline for optimal growth).

For saline-tolerant crops, new plant genomic studies have defined two salt-tolerant genetic loci (genes) in tomato *TSS1* (a potassium ion transporter) and *TSS2* (a component of the abscisic acid plant hormone signalling pathway). Either or both would be good candidates for GM; putting an existing food plant gene into a salt-intolerant food crop.

Quality of life issues - women in LDCs spend 80% time weeding. (60% of the labour in maize production in Zimbabwe was weeding)

Food Quality Issues
Consumers demand ever-greater variety, all-year-round supplies of uniform, blemish-free produce, plus safe and competitively-priced food.

Safety Issues

No single example of GM being harmful to human health (after 6 years of extensive consumption - trillions of meals); despite orchestrated food scare campaigns - e.g. Frankenfoods, Gerber, Nestle, Iceland Foods UK, Starlink (Cry9C) tacos.

GM can actually remove **a**nti-nutritionals (natural toxins, antifeedants such as cyanogenic glycosides in cassava) and reduce the concentrations of carcinogenic mycotoxins (e.g. aflatoxins) caused by fungal invasions of corn plants already damaged by feeding of stem borer larvae etc.

GM can eliminate known allergenic proteins as found predominantly in wheat, soyabeans, peanuts, tree nuts (and probably also in fish, shellfish, milk and eggs).

Shelf-life and Food Miles

Post-harvest storage losses can be 10-100%, due to poor storage, pests, and transport. All year round availability requires rtificial environments
Ripening inhibitors/promoters
Growth regulators

Shelf-life issues - Malaysian favorite “Eksotika” papayas, can delay post-harvest ripening from 2 to 4 weeks by inserting an antisense ACC oxidase gene which lowers endogenous ethyene (ripening hormone) production levels to allow access to US and EU markets.

Novel Output Traits (metabolic engineering)
See future of agriculture as an essential part of healthcare; e.g. beta-carotene/pro-vitamin A “Golden Rice/Mustard” had phytoene synthase (daffodil) phytoene desaturase (*Erwinia uredovora*) and lycopene beta-cyclase (daffodil) genes inserted. GM tour de force. Globally, 100-200 m children affected by VAD, 1 million die and 0.5 million go blind p.a., moslty those on high rice diet. Also developed a GM high iron rice (bean

ferritin, a storage protein gene), a fungal phytase gene (releases Fe from phytate), and a cysteine-rich metallothionein gene. Targeted at women suffereing from anaemia.

Tomato lycopene (antioxidant) and other flavonoids, antioxidants which the decrease risk of cardiovascular disease. GM tomato with Petunia gene (chalcone isomerase) raised the flavonoid concentration 78-fold in peel (to level in onion skin) and 21-fold up in processed tomato paste compared with non-GM tomato (Unilever).

Next revolution will emerge from post-genomic era. Transgenic plants that defend themselves against pests or pathogens, or abiotic stresses only in the relevant target organs (e.g. roots) by spatially and temporally regulated expression of natural endogenous resistance pathway genes.